MONTGOMERY COUNTY
SOLID WASTE MANAGEMENT SYSTEM
FY07 MARGINAL COSTS

Purpose

A marginal cost is defined as the cost to produce one more unit of production. In the context of Solid Waste Management, a tonnage-related marginal cost is the cost to manage *one more ton* of waste. Since solid waste management involves a variety of activities, a variety of marginal costs influence system-wide effects on County costs.

There are at least three reasons for examining our system's tonnage-related marginal costs. First, achieving our 50% recycling goal will require an additional 100,000 shift in the disposition of waste, from disposal to recycling. Knowledge of marginal costs can help forecast the changes in system-wide costs that may result from various changes or shifts in tonnage. Secondly, substantial variances can (and do) arise between budgeted and actual expenditures due to tonnage-related circumstances beyond the County's direct control. Knowledge of marginal costs can help managers anticipate fiscal consequences of both the negative and positive variances. Finally, the County's Comprehensive Solid Waste Management Plan, ("10 Year Plan") requires the Department to prepare "a discussion of the marginal costs of increased recycling." [1] This paper serves all of these purposes. The terms "marginal" and "incremental" are synonymous.

Summary Results

Exhibit 1 summarizes the overall effects, in FY07 dollars, for a variety of cases, expressed as "what if" questions. Values in parenthesis indicate County savings.

Exhibit 1
What Happens to Ovearall County Costs If…

Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?	***$***	***(16.67)*** */ ton avg. deliverable waste*
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?		
RMP < 90,000 TPY	***$***	***(6.13)*** */ ton of paper shifted*
RMP > 90,000 TPY	***$***	***8.32*** */ ton of paper shifted*
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?	***$***	***(36.01)*** */ ton of commingled*
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?		
RMP < 90,000 TPY	***$***	***(13.15)*** */ ton increased recycling*
RMP > 90,000 TPY	***$***	***(2.10)*** */ ton increased recycling*

Note: Assumes all waste that is processible at the RRF, and delivered to the County for disposal, are processed at the RRF and exceed 558,450 tons, evenly distributed c
All costs expressed in FY07 dollars.

[1] Division of Solid Waste Services, Ten Year Plan 2004-20013, Section 5.2.4.3. Note that a related requirement, found in Section 5.2.4.3 of that Plan, is to report the "estimated per unit costs for major County solid waste programs and facilities". The term "unit cost" (as distinct from "marginal" or "incremental") refers to an average cost per ton during a fiscal year. For unit costs, see Full Cost Accounted Annual Average Unit Cost Trends in Montgomery County, Maryland, Solid Waste Management, DSWS, October, 2006.

A general result of this analysis is that a shift in recyclable materials, from trash can to recycling bin, can be expected to save the County money, at least in estimated FY07 budget cost dollars.[2] As can be seen in Exhibit 1, the results with respect to questions 2, 3, and 4 (Q2, Q3, and Q4), generally predict County savings with that savings depending upon which types of materials are shifted (e.g. commingled containers or residential mixed paper, or both). An exception to this generalization of savings is a special case in which only residential mixed paper (RMP) is shifted and the total annual RMP recycled through the County facility exceeds 90,000 tons (Q2 with RMP>90,000 tons/year).[3]

Another result of this analysis answers the question, Q1, "What happens to overall County costs if one *less* ton of typical waste is delivered for disposal to the County with no change in recycling?" The answer it about $16.67 per ton of typical waste delivered for disposal.

The summary results in presented Exhibit 1 should not be applied without recognizing their derivation and the pertaining assumptions and qualifications, which are discussed below.

For example, the results depicted in Exhibit 1 assume annual tonnage throughput at the County's Resource Recovery Facility (RRF) consistent with current County policy (e.g. that the RRF process between 558,000 and 604,000 tons per year, or 85 and 92 percent of that facility's permitted capacity).[4] However, the County's estimated system-wide marginal costs differ substantially, when it is assumed that the annual tonnage of RRF-processible waste delivered to the County for disposal is less than 558,450 tons or, on the other hand, exceed RRF capacity and must be landfilled. Results applicable to those lower, and higher, tonnage ranges are included for completeness, and to check on the robustness of numerical results a variety of additional cases test variations in the underlying assumptions.

Methods and Analytic Approach

The County's Sold Waste Management System is comprised of many components. Some components manage different types of waste, with associated expenditures varying as a predictable function of tonnage. Many of these tonnage-cost relationships are well-defined, such as those specified by the terms of County operating contracts. Major system components with such contract-specified tonnage-cost relationships include: processing of Residential Mixed Paper (RMP), waste processing at the Resource Recovery Facility (RRF), and the County's contract for out-of-county disposal of materials that must be landfilled. In addition, the County's contract cost for operating its commingled container materials recovery facility (MRF), while not defined in terms of any $/ton parameters, can be estimated to be somewhat tonnage-related (e.g. not all fixed costs), and all materials recovered at that MRF are sold on the basis of dollar-per-ton pricing. The costs of most other County solid waste management activities (e.g. administration and debt service), can be taken as relatively unresponsive to changes in tonnage experienced by the system. Also, tonnage relationships exist among different system components, introducing additional considerations.

[2] The costs in this report are based on the same estimates used in preparing the County's FY07 budget.
[3] During FY06, the County recycled approximately 76,500 tons of RMP through its paper acceptance facility.
[4] Montgomery County, Division of Solid Waste Services, Ten Year Plan 2004-20013, Comprehensive Solid Waste Management Plan, Section 5.2.1.2(f)2.

The analytic approach of this report is as follows:

1. Identify contract-specified relationships between tonnage and County cost;
2. Identify any other potentially significant tonnage-cost relationships (e.g. those not specified in contract terms but for which a theoretical relationship can be reasonably well-founded);
3. Combine those relationships to recognize net system-wide effects and reveal overall system incremental costs that can be expected, based on contract terms, to result from potential near-term changes or shifts in tonnages;
4. Examine the sensitivity of those system-wide results to the effects of less-certain tonnage-cost relationships (e.g. those not contractually specified such as net-of-revenue MRF operating costs);
5. Apply sensitivity analysis to examine the effects of variation in the tonnage-tonnage relationships employed (e.g. potential error in derived values for ash fractions of paper and commingled containers); and
6. Examine the significance of second-order effects on the incremental cost of RRF processing potentially mediated by changes in the energy or ash content of waste delivered for disposal as may be engendered by the diversion from disposal to recycling of specific species components of waste.

It is important to make one more note as to the analytical approach of this paper, and this is with respect to the direction of causation underlying the marginal costs derived. This paper examines the effects <u>of</u> tonnage <u>on</u> costs; it does not attempt the reverse. A reverse causation may or may not exist. That is, an increased expenditure in say, education or enforcement, may be intended to engender a shift in tonnage from disposal to recycling, however, this paper makes no attempt to predict what changes in tonnage might be reasoned to later result from a changing budgetary expenditure. The marginal costs derived in this paper reflect the effect of marginal changes in tonnage→on→cost, and not the other way around. On the other hand, consideration of the marginal costs derived here can aid in evaluating the cost-effectiveness of expenditures intended to bring about shifts in tonnage.

1. Contract-Specified Tonnage-Cost Relationships

Montgomery County experiences contract-specified tonnage-related costs within three of its budgetary programs. These programs are:

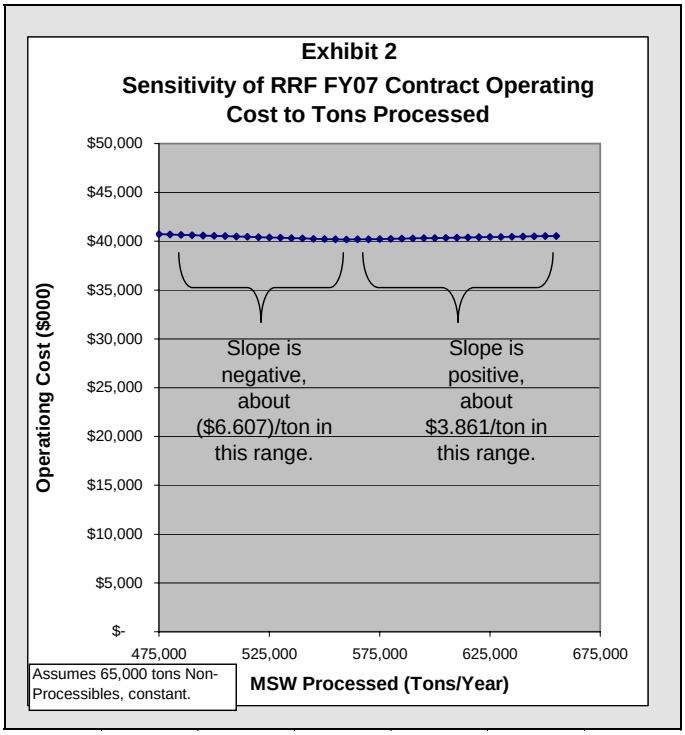
- Residential Mixed Paper Recycling Program,
- Resource Recovery Facility (RRF) Program, and
- Out-of-County Hauling Program.

<u>Residential Mixed Paper Recycling Program:</u> This budgetary program houses the County's long-term operating contract with Office Paper Systems, Inc. (OPS) for accepting, processing and marketing all residential mixed paper (RMP) delivered by or on behalf of the County's residential recycling collection programs. Until 90,000 tons per year of RMP are recycled the *incremental* cost of RMP processing is zero. This is an artifact of the County's processing contract wherein the County pays a specified amount per year, until RMP deliveries exceed 90,000 tons per year. For RMP tons greater than 90,000 per year,

each additional ton of RMP costs the County $14.45 (FY07, indexed to inflation) to accept, process and market the RMP.

Out-of-County Hauling Program: The cost for transportation and ultimate disposal of ash is budgeted in the Out-Of-County (OOC) Program. The OOC Program also includes costs for transporting to an out-of-county landfill, and ultimate disposal, of all non-processible (NP) waste accepted by the County, as well as for any "By-Pass" waste. By-Pass waste is waste that is accepted on to the tipping floor of the Transfer Station, of the type able to be processed at the RRF ("processible waste"), but elected not to be delivered to the RRF for processing. The contract prices for this service are indexed to inflation and change every October 1. The factor $39.07/ton is estimated to represent a blended average over FY07 assuming uniform delivery of tonnage over the year. It applies to both ash and NP tons over the tonnage ranges considered. This factor does not account for "surge" or other minor charges that may apply (e.g. when there is uneven delivery and a sudden need for additional trucking). Finally, there is separate pricing—estimated to be $33.40/ton for FY07—which applies to haul materials such as dirt, rock and asphalt to local recyclers who can sometimes accept such materials. This latter factor will not enter into subsequent analysis as such materials are not included in the County's recycling rate.

Resource Recovery Facility (RRF) Program: Work covered by contract costs budgeted within the RRF Program includes receiving all waste at the County's Transfer Station (TS), compacting processible waste for inter-modal transport, rail transport to and processing at a waste-to-energy facility, and recovery of ferrous materials at that facility. The RRF Program budget does not provide for transportation and disposal of the solid residue (ash) remaining after processing. Exhibit 2, to the right, illustrates the influence of annual tonnage processed on FY07 contract costs within the RRF Program. For any given annual tonnage, the slope of the line represents the incremental cost (incremental dollars per incremental ton processed) at that tonnage. The discontinuity in slope at 558,450 tons per year is an artifact of the contract representing facility design as well as contract matters. Above that 558,450 annual throughput, the incremental RRF cost (the slope of the cost curve) is about $3.86 per incremental ton processed. (Actually, over that tonnage range from 558,450 to 655,000 the cost per incremental ton ranges from about $3.93 to about $3.81 per incremental ton). Below that 558,450 discontinuity in the cost curve, and down to well below 530,000 TPY, the cost to the County is, negative, with a value of about -$6.61/ton. (*Plotted results are based on the Division's budget modeling of the RRF Service Agreement as of March, 2006, which necessarily contains estimates for parameters, such as indexed inflators, that can only be*



ascertained at the end of the year. However, the slope of the line should be a fairly reliable indication of the County's incremental cost for processing waste at the RRF.)

The County also receives, at its Transfer Station (TS), waste that is not of the type which is processible at the RRF ("non-processible" or "NP" waste). As a component of its RRF operating contract, the County pays its RRF operator for activities that the RRF operator carries out at the TS. These include handling NP on the tipping floor and loading-out NP waste onto trucks of another contractor for out-of-County haul. There is also a component within the RRF contract to cover the contractor's cost of handling and loading-out By-Pass waste. While conditions for By-Pass waste are not expected during FY07, the potential circumstance is included in the analysis for completeness.

2. Other Potentially Significant Tonnage-Dependent Costs

Other programs were examined for potential tonnage-dependent costs, include:

- The Materials Recycling Facility (MRF) Program;
- The Refuse Collection Program;
- The Recycling Collection Program; and the
- The Yard Trim Composting Program.

Materials Recycling Facility (MRF) Program: The MRF Program refers to County's activities of processing and marketing commingled container-type materials. The County subcontracts MRF operation and County costs under that contract are not expressed in tonnage-variable terms. (The County pays all actual costs of MRF operation and receives all material revenues.) MRF operating costs, no doubt, include some cost components that vary, more or less, with tonnage and others that are essentially fixed with respect to tonnage, but distinguishing which costs are tonnage-variable is a matter of conjecture. In addition, revenues from the sale of MRF materials can be viewed as offsetting MRF operating costs. However, unit sales prices are indexed to external markets, adding uncertainty. For these reasons, MRF incremental operating costs are taken as zero in the first instance, and then after first examining system-wide effects of contract-specified incremental costs in budgetary programs (for which there is relative certainty), this report then examines theoretical MRF incremental costs and their potential effect on the overall County cost.

Curbside Refuse and Recycling Collection: County curbside refuse and recycling collection services are also provided by contracts between the County and private companies. The costs to the County are defined in these contracts as monthly costs *per household* served. These "unit-costs" are indexed to inflation and are fairly predictable over 5 to 7-year contract periods, but they are *not* indexed to tonnage other than with respect to a one-time incentive provision now contained in each County recycling collection contract, which provides a one-time $30/incremental ton/year incentive to the contractor. Because this is a one-time feature, and contractors differ as to where they stand with respect to the initial achievement, this factor is not included in the "combining" analysis in Section.

Yard Waste Composting Program: The County's yard waste composting facility is operated by a subcontractor, and that contract does not define County costs in terms of tonnages. However, by agreement with the Sugar Loaf Citizens' Association, for any tons requiring composting in excess of 77,000 ton per year, the County must utilize alternate

facilities. Currently, the County has back-up contracts for yard waste composting, with County costs defined in terms of per-ton amounts ranging from $18/ton to $42/ton. These factors can be taken to represent the range of County incremental costs for composting yard trim in excess of 77,000 tons per year. Due to the effectiveness of the County's yard waste ban, however, there is very little yard waste found in disposed waste, and thus little opportunity to shift yard waste from the disposed waste stream. Therefore, incremental yard waste composting costs are not included in the systems analysis that follows.

All other County program costs were considered as not predictably variable as a function of tonnage over the tonnage ranges considered. Exhibit 3, below, lists incremental cost components used to derive results that appear in Summary Exhibit 1, above.

EXHIBIT 3

TONNAGE-VARIABLE INCREMENTAL COUNTY COSTS

(Expressed in FY07 dollars)

VARIABLE COSTS BY BUDGETARY PROGRAM:					
	Comment or Condition		$ Added	per ton of what?	Ref.
Residential Mixed Paper (RMP) Processing & Marketing					
	RMP < 90,000 TPY	$	0.00	/ ton of RMP	A
	RMP > 90,000 TPY		$14.45	/ ton of RMP	B
Materials Recovery Facility (MRF), Processing and Marketing Commingled Containers					
	Not contractually defined, see "Sensitivity Analysis"	$	0.00	/ ton of commingled containers	C
Out-Of-County Haul					
	Contract cost to haul and dispose of ash & NP, long-term agreement:		$39.07	/ ton hauled out of County	D
	Ash as fraction of processed tons 30.47%		which converts to		E
		$	11.90	/ ton of typical processibe waste	F
Resource Recovery Facility					
Added Cost Per Incremental Ton of Processible Waste	530,000 < TPY < 558,450	$	(6.61)	/ ton of typical processibe waste	G
	558,450 < TPY < 650,000	$	3.86	/ ton of typical processibe waste	G1
	Adder for Covanta NP tons at 6.6% of processible waste, if applicable	$	0.90	/ ton of typical processibe waste	G2
	Covanta charge for handling any By-Pass tons at Transfer Station	$	13.70	/By-Pass ton (processible to LF)	G3

Notes/Refs.

A OPS Contract

B OPS Contract with 3.3% ECI inflation assumed for FY07 budget

C See "Sensitivity Analysis" in this report for consideration of a thoretical value for this parameter and its potential system effects.

D Allied Inc., Out-of-County Haul Contract per-ton cost, as reflected in FY07 Budget. Does not include surge waste cost or simiilar charges.

E FY06 tonnages ratio assumed in FY07 budget models (ratio of ash tons outgoing / incoming processible tons)

F = D x E

G RRF Contract (Northeast Maryland Waste Disposal Authority, Waste Disposal Agreement), with FY07/FY06 contract inflators estimated.

G1 "

G2 "

G3 " . By-Pass tons = Processible waste accepted at the Transfer Station but not sent to the RRF, and landfilled instead.

In and of themselves, the above incremental costs tell only how the costs for each of several *isolated system components* vary with the tonnage experienced *by that component*. Changes or shifts in tonnage can influence costs in more than one system component or budgetary program. Thus, the overall effects on County system cost cannot be assessed without recognizing important tonnage-tonnage relationships between the component cost centers, or cross-program effects.

One such relationship, already noted in Exhibit 3, is that for every 1.00 tons of waste processed at the RRF, 0.3047 tons of ash remains needing to be disposed. (The RRF reduces the weight of waste required to be landfilled by 69.53%.) Thus, the incremental ash disposal cost of $39.07 *per ton of ash disposed* is equivalently expressed in terms of incremental tons processed at the RRF as $11.90 *per ton of typical processible waste*.

Other tonnage-tonnage relationships arise from the non-homogeneity of waste, and the fact that some system components (e.g. residential paper and commingled container processing) operate on selected components of the waste stream. These will be addressed in the next section.

Before proceeding, note that Exhibit 3 lists the incremental MRF costs as zero, with the notation "Not contractually defined, See Sensitivity Analysis". The approach taken in this report is to first examine system-wide effects on the relatively strong basis of well-defined *contract terms*, and then examine the potential effects less well-defined and necessarily more *theoretical* estimates. As will be seen, estimated incremental MRF operating costs, net of revenue are potentially very substantial, but fall into the relatively theoretical category.

3. Combined Effects

As noted above, changes or shifts in tonnage can influence costs in more than one system component or budgetary program. The following series of exhibits will illustrate how the foregoing individual component marginal costs can be *combined* to recognize influences on overall County system costs. To make the exercise useful, but not too burdensome, this will be done for a number of hypothetical cases of interest and recognizing a wide range of potential conditions. Each exhibit tells how overall County costs would change in response to four generic types of changes in tonnage, answering four questions (Q) — each beginning with "What happens to combined County costs….":

Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?

Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?

Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?

Q4 …if one ton, comprised of both paper and containers (typical mix), is SHIFTED from trash can to recycling bin?

The hypothetical circumstances underlying these questions incorporate the assumptions of "all-else-being-equal". In addition, in the case of Q1, it is also assumed that recycling tonnages through County system components other than the RRF and OOC programs remain constant or are unaffected by the variation in the tonnage delivered to the County for disposal. A circumstance consistent with these assumptions would be that of constant waste generation and constant recycling, accompanied by an increase in private sector waste exportation to out-of County disposal locations. In the cases of Q2 and Q3 it is assumed that waste generation remains constant and that likewise waste exportation by private sector collectors remains constant, such the tonnage is shifted, ton-for-ton, *among County system components* (e.g. one ton is shifted from being delivered to the County Transfer Station for disposal, to being delivered to the County Recycling Center for recycling.

Each of the following three exhibits answers all four questions, but under different assumptions as to RRF throughput. Recall, as indicated in Exhibit 3, that the marginal costs of some system components (e.g. RRF and RMP processing) differ depending on the range of

annual tonnage managed by that component. Therefore, combined, overall system incremental costs will likewise differ depending upon the annual tonnage experienced by subject components. A separate exhibit is provided for each of three annual tonnage ranges relative to RRF-processible waste received by the County, and each exhibit includes results for both RMP circumstances (greater or less than 90,000 tons). In this way, a total of eighteen hypothetical cases are systematically presented.

In order to combine component marginal costs to assess overall system effects, three tonnage-tonnage relationships were required. These are expressed in terms of weight fractions:

- the ash fraction of RMP,
- the ash fraction of a typical mix of commingled materials, and
- the container fraction of total RMP tonnage plus container tonnage typically received.

In the above, "ash fraction" refers to the contribution of the waste constituent to RRF residue assuming that constituent is delivered to the RRF. The ash factor of RMP is derived in Appendix A, based on recent technical journal values and other reasonably reliable sources yielding an estimate of about 5.81%. The ash fraction of mixed commingled material is derived in Appendix B based on the relative composition of commingled materials as experienced at the MRF during FY05, and the ash content type of each container material. Finally, the weight fraction of total materials receive at the MRF comprised of just container-type materials was found to be 0.235. That is, container-type materials delivered to the County MRF tend to represent 23.5 weight percent of total tons received at the MRF. This mass fraction is derived based on actual FY05 tonnages, and is typical. Applying these weight fractions, the derivation of combined results, detailed in Exhibits 4a, 4b and 4c, by algebraic reference, is self-explanatory.

EXHIBIT 4a

COMBINED EFFECTS WITH RRF PROCESSING 530,000 TO 558,450 TONS / YEAR

(Expressed in FY07 dollars)

What happens to combined County costs?.....					
			.....County cost increases (decreases) by this amount:		Ref.
Q1 ...if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?					
	Applicable Range:	530,000 < TPY < 558,450	**$**	**(6.20)** / ton typical deliveable waste	H
Q2 ...if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?					
	Assumption:	Ash as % of RPM =	5.81%		I
		RMP < 90,000 TPY	**$**	**4.34** / ton of paper shifted	J
		RMP > 90,000 TPY	**$**	**18.79** / ton of paper shifted	K
Q3 ...if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?					
	Assumption:	Ash % of commingled containers =	82.3%		L
			$	**(25.55)** / ton of commingled	M
Q4 ...if one ton, comprised of both paper and containers (typical mix), is SHIFTED from trash can to recycling bin?					
	Assumption:	Container fraction =	23.5%		N
		RMP < 90,000 TPY	**$**	**(2.69)** / ton increased recycling	O
		RMP > 90,000 TPY	**$**	**8.37** / ton increased recycling	P

Notes/Refs.

H = - F - G - G2
I See Appendix A
J = A - G - (I x D)
K = B - G - (I x D)
L See Appendix B
M = C - G - (L x D)
N Reflects the ratio of actual FY05 tonnages
O = N x M + [(1-N) x J]
P = N x M + [(1-N) x K]

Exhibit 4a, above, corresponds to the circumstance where annual RRF tonnage is between 530,000 and 558,450 tons. However, the County has not received RRF-processible tonnage in that range since fiscal year 2001.

Exhibit 4b, below, corresponds to the case where the RRF annual tonnage is between 558,450 and its calendar year permit limit of 657,000, and all RRF-processible waste delivered to the County for disposal is processed at the RRF (e.g. the County ships no processible waste to landfilling).

EXHIBIT 4b
COMBINED EFFECTS WITH RRF > 558,450 tons (but Still No By-Pass)
(Expressed in FY07 dollars)

What happens to combined County costs…..			Ref.
	Answer: County Cost increases (decreases) by this amount:		
Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?			
Applicable Range: 558,450 < TPY < 650,000	**$ (16.67)** / ton average deliverable waste		H1
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?			
Assumption: Ash as % of RPM = 5.81%			I
RMP < 90,000 TPY	**$ (6.13)** / ton of paper shifted		J
RMP > 90,000 TPY	**$ 8.32** / ton of paper shifted		K
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?			
Assumption: Ash % of commingled containers = 82.3%			L
	$ (36.01) / ton of commingled		M
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?			
Assumption: Container fraction = 23.5%			N
RMP < 90,000 TPY	**$ (13.15)** / ton increased recycling		O
RMP > 90,000 TPY	**$ (2.10)** / ton increased recycling		P

Notes/Refs.
H1 - F - G1 - G2
I See Appendix A
J A - G1 - (I x D)
K B - G1 - (I x D)
L See Appendix B
M C - G1 - (L x D)
N Reflects the ratio of actual FY05 tonnages
O N x M + [(1-N) x J]
P N x M + [(1-N) x K]

As alluded to earlier, County policy, for RRF tonnage, is that "the annual target for processible waste to the facility is in the range of 85 and 92 percent of permitted capacity, or 558,450 and 604,440 tons per year".[4] Among the three exhibits in this series, Exhibit 4b, above, represents annual RRF tonnage conditions most consistent with that policy target.

Both preceding cases assume no landfilling of RRF-processible waste. Any landfilling of processible waste delivered to the County is termed "by-pass waste" and results in different County costs, due to its handling by the RRF contractor without the benefit of processing at the RRF and weight reduction. The last exhibit in this series examines the system in by-pass mode.

For the purpose of Exhibit 4c, below, it is assumed that RRF tonnage remains constant (e.g. at or near its permitted capacity limit) and that the only changes in disposed tonnage are in the amount of by-passed tonnage. This is a theoretical but useful construct. An operating permit limit of 657,000 tons per year (TPY) sets the regulatory upper bound to RRF processing.

EXHIBIT 4c

MBINED EFFECTS WITH RRF "FULL"; EXCESS PROCESSIBLE WASTE IS LANDFILL

(Expressed in FY07 dollars)

What happens to combined County costs …..

Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?				
		Then, County Cost increases (decreases) by…		Ref.
	Applicable Range: greater than 657,000	***$***	***(52.77)*** */ ton avg. deliverable waste does not inlcude surge charges*	P
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?				
	Applicable Range: RMP < 90,000 TPY	***$***	***(39.07)*** */ ton of paper shifted*	J
	RMP > 90,000 TPY	***$***	***(24.62)*** */ ton of paper shifted*	K
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?				
		$	***(52.77)*** */ ton of commingled*	M
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?				
	Assumption: Container fraction = 23.5%			N
	Applicable Range: RMP < 90,000 TPY	***$***	***(42.29)*** */ ton increased recycling*	O
	RMP > 90,000 TPY	***$***	***(31.23)*** */ ton increased recycling*	P

Notes/Refs.

P = - D - G3
J A - D
K B - D
M C - D - G3
N FY05 actuals
O N x M + [(1-N) x J]
R N x M + [(1-N) x K]

It should be noted that in a year when the TS receives more than *approximately* 650,000 tons of processible waste, as a practical matter at least some of that processible waste should be expected to be by-passed, the specific amount depending on a variety of year-specific temporal factors. In such a year, the results of Exhibit 4c would be most useful if considered in combination with those of Exhibit 4b.

Finally, readers interested in isolating cost effects on the County's *disposal system* may observe (as necessarily follows from the fact that reference items A and C in Exhibit 3 were taken to be zero) that, except for cases where RMP exceeds 90,000 tons per year, all of the numerical results in these preceding exhibits exclusively reflect effects on components of the County's disposal system.

Until now (e.g. with respect to all three preceding exhibits), we have assumed that MRF incremental costs are zero. Sensitivity to that assumption will be examined in the next section.

4. Sensitivity to Estimated MRF Net-of-Revenue Incremental Costs

The preceding marginal cost results have rested on the relative certainty, from a budgetary standpoint, of contract terms and sound physical relationships. For a number of reasons, however, the preceding results should be regarded as conservative. First, the County receives 100% of container material sales revenues, which revenues, while subject to market uncertainties have been substantial; the cost of MRF operations is always offset, at least somewhat, by material sales revenue. Moreover, extensive process improvements completed in recent years, in including redundancy in critical processes and plastics sorting capability together with strong markets, has resulted in revenues that exceed all MRF contract operating costs. Finally, tonnage-variable costs, although not contract-specified, can be at least

theoretically estimated to represent a substantial portion of MRF operating cost. Thus, it can be estimated with increasing assurance, that Exhibit 1 represents conservative results; any consideration of net-of-revenue MRF incremental costs only improves the outlook for overall County savings in the circumstances hypothesized by questions Q3 and Q4 (involving shifts of commingled container tonnage away from waste processed at the RRF and toward the MRF). This, in and of itself, is meaningful, but it also may be useful to develop a theoretical estimate of what the net-of-revenue MRF incremental operating costs might actually be.

The County's MRF operating contract, while not defining County costs in terms of costs per ton processed, requires the contractor to submit highly detailed invoices with full back-up. Informed by that detail, and applying judgment as to which types of costs might be expected to vary with tonnage and which not, one can develop a theoretical basis for estimating tonnage-varying MRF marginal costs. Appendix C applies this approach. Types of cost deemed variable with tonnage were as follows: maintenance and repair of rolling stock (e.g. fork lifts), equipment repair and maintenance, one-half of building and road repair, all contract labor, repair parts, grease and lubricants, baler consumable materials, and one-half of electricity bills. During FY05, those costs subtotaled to $1,141,579 (about half of total contract operating cost), and during that same period, there were 22,037 tons of material processed. Dividing the first figure by the latter, and applying estimated inflation (2.3% for FY06 and 2.6% for FY07), yields a theoretical incremental operating cost of $54.37/ton in FY07 dollars. Against this incremental operating cost, one may credit material sale revenues. All materials are sold on a $/ton (e.g. negative incremental cost) basis. In FY05, total material sales revenues were $3,146,213. Normalizing this total revenue to that same outgoing tonnage of 22,037 gives an "average unit material sales revenue" (negative incremental cost) of $142.77 per ton of MRF throughput. This revenue more than offsets the theoretical $54.37/ton MRF incremental operating cost, yielding a net-of-revenue MRF marginal cost of *negative* $88.40/ton (e.g. the County benefits by about $88.40 for each additional ton of typical commingled mix recycled through the MRF). See Appendix C for full derivation of this theoretical FY07 value.

That result considers the MRF (and its revenues) in isolation, as if the incremental commingled materials arrived out of thin air, from some unrelated source; it does not recognize changes in County costs experienced in other system components, such as may give rise to the added MRF throughput tonnage by virtue of a shift from trash can to recycling bin.

What combined changes in system-wide costs arise from such shifts are the subjects of question Q3 and Q4. Previous answers ignored potential MRF marginal costs (conservatively assumed, then, to be zero). Before presenting the implications of our theoretically developed net-of-revenue MRF incremental cost, Exhibit 5, below replicates, for quick reference, those preceding results that assumed zero MRF incremental operating costs.

Exhibit 5 – Summary of Exhibits 4a, 4b and 4c; Assumes MRF Marginal Cost = 0

COMBINED RESULTS; What happens to County Costs If…

	Assumes Processible tons between 530,000 and 558,450	Processible tons > 558,450 and processsed all at RRF	Assumes all Incremental Tons Effect By-Pass Tonnage
Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?	***$ (6.20)***	***$ (16.67)***	***$ (52.77)*** */ ton avg. deliverable waste does not inlcude surge charges*
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?			
RMP < 90,000 TPY	***$ 4.34***	***$ (6.13)***	***$ (39.07)*** */ ton of paper shifted*
RMP > 90,000 TPY	***$ 18.79***	***$ 8.32***	***$ (24.62)*** */ ton of paper shifted*
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?	***$ (25.55)***	***$ (36.01)***	***$ (52.77)*** */ ton of commingled*
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?			
RMP < 90,000 TPY	***$ (2.69)***	***$ (13.15)***	***$ (42.29)*** */ ton increased recycling*
RMP > 90,000 TPY	***$ 8.37***	***$ (2.10)***	***$ (31.23)*** */ ton increased recycling*

(Expressed in FY07 dollars)

Exhibit 6, below, shows the alternate set of results obtained by substituting the theoretically derived MRF marginal cost of negative $88.40/ton for the $0/ton value at reference C in Exhibit 3. The answers to questions Q3 and Q4 are changed substantially, underscoring the potential added benefits of increased diversion of recyclable container-type materials from disposal in trash to recycling via the County MRF.

Exhibit 6
Alternate Results Assuming Theoretical MRF Marginal Cost of Negative $88.40/ton

COMBINED RESULTS; What happens to County Costs If…

	Assumes Processible tons between 530,000 and 558,450	Processible tons > 558,450 and processsed all at RRF	Assumes all Incremental Tons Effect By-Pass Tonnage
Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?	***$ (6.20)***	***$ (16.67)***	***$ (52.77)*** */ ton avg. deliverable waste does not inlcude surge charges*
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?			
RMP < 90,000 TPY	***$ 4.34***	***$ (6.13)***	***$ (39.07)*** */ ton of paper shifted*
RMP > 90,000 TPY	***$ 18.79***	***$ 8.32***	***$ (24.62)*** */ ton of paper shifted*
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?	***$ (113.94)***	***$ (124.41)***	***$ (141.17)*** */ ton of commingled*
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?			
RMP < 90,000 TPY	***$ (23.46)***	***$ (33.93)***	***$ (63.06)*** */ ton increased recycling*
RMP > 90,000 TPY	***$ (12.40)***	***$ (22.87)***	***$ (52.01)*** */ ton increased recycling*

(Expressed in FY07 dollars)

Nothing has been said, thus far, about the range over which that Appendix C result might be applicable. Unfortunately, the methodology used yields no insight as to the range over which such a theoretically derived net-of-revenue MRF marginal cost might be applicable. All that can be said with confidence is that the derived value becomes even more theoretical with increasing (or decreasing) MRF throughput relative to the 22,037 tonnage upon which it derived. At this point, then it is instructive to posit what potential added MRF tonnage might be available via diversion form the disposed waste stream. The County's latest waste composition study indicated that approximately 4.75% of the total disposed Municipal Solid Waste (MSW) waste stream was comprised of recyclable containers, suitable for MRF processing (5.75% in the case of single-family MSW disposed). Applying these fractions to the

County's FY05 System-Wide Material Flow Accounting, single-family homes disposed of 245,500 tons in FY05 (1 ton/home). This suggests the possibility, in the extreme, of the MRF receiving an additional 35,300 tons per year of container-type material, including a maximum of 14,100 from the single-family sector (assuming 100% capture for recycling of all container materials generated). It is doubtful that the theoretically-derived marginal cost figure derived in Appendix C would apply over much of that range. During FY06, approximately 22,000 tons of commingled materials were recycled through the MRF, nearly fully utilizing its one-shift capacity, and to date, the MRF has operated on only one 8-hour shift per day. Substantially increased MRF tonnage would likely require added managerial and other costs, treated as fixed costs (e.g. not varied with tonnage) in Appendix C, plus possibly, the addition of a second shift. Thus, it must be cautioned that both tonnage-based MRF incremental operating costs and per-ton revenues are not well defined; the net-of-revenue MRF incremental operating cost derived here, while substantial, must be considered highly theoretical, though potentially substantial.

Additional Sensitivity Analyses

Results in Exhibits 4a and 4b, in the preceding text, utilized factors representing tonnage-to-tonnage relationships derived from theory. These factors were: (a) the ash fraction, by weight, contained within Residential Mixed Paper, and (b) the ash fraction, by weight, comprising a standardized commingled container mix. Appendix D examines the sensitivity of the results reported above to errors in those factors, and shows that the effects of increasing each of these factors by 10% (a degree of error thought to be unlikely.) The overall effects are not large. Increasing the estimated ash fraction of RMP by 10% (e.g. from 5.81% to 6.41%) reduces the answers to Q2 in Exhibit 4a and 4b by $0.23/ton, and Q4 in those exhibits by $0.17/ton. Increasing the assumed ash fraction of commingled containers recycled by 10% (e.g. from 82.3% to 90.53%) reduces the answers to Q3 in Exhibit 4a and 4b by $3.22/ton, and Q4 in those exhibits by $0.76/ton.

Appendix E examines potential secondary, or non-linear, effects on RRF operations, which effects might result from the changing composition of the waste disposed, and thus delivered to the RRF for processing. Two potential effects are assessed. One is the effects of increased recycling on the higher heating value (HHV) of disposed waste. (The HHV of a material is defined in terms of its extractable energy content per unit of mass, typically expressed in terms of Btu/lb). The other secondary effect evaluated is that of recycling on the ash content of waste delivered to the RRF and thus its ash generation rate. Based on the calculations in Appendix E, second-order HHV effects are quite small, effects from container recycling being larger than those of RMP recycling, but changing the Exhibit 3 values for G1 and G2 by more than about 11 cents per ton, as follows.

Adjustments to G1 & G2 With Increasing Container Material Diversion

Tons Diverted	5,000	10,000	15,000	20,000	25,000	30,000	35,000
Adjustment	$ (0.02)	$ (0.03)	$ (0.05)	$ (0.06)	$ (0.08)	$ (0.10)	$ (0.11)

Negative values indicate additional savings to the County with increasing container diversions, but the effect is so small as to be considered insignificant. For example, once an additional 10,000 tons of commingled container-type materials is diverted from the waste otherwise headed for the RRF, all other conditions being equal, the County's marginal costs for RRF processing would be $0.03/ton lower than indicated in Exhibit 3.

Conclusions

Increased recycling has been shown to have favorable estimated system-wide County fiscal effects, and this is especially the case if theoretically estimated MRF net-of-revenue incremental operating costs are included. For example, on the basis of well-defined contract costs, as in Exhibit 5, it can be seen that a budgetary initiative of $13,150 could be regarded as cost-effective (e.g. fiscally neutral in its system-wide effects) if that expenditure reasonably could be expected to engender an increased single-family curbside recycling setout of 1,000 tons of typical paper and container mix. (Equivalently, the same conclusion applies if the expenditure reasonably could be forecasted to *avoid a decline* in those recycling setouts.) Alternatively, on the basis of Exhibit 6, which includes very theoretically estimated net-of-revenue incremental MRF operating costs, a projection of 1,000 tons of increased recycling (or avoided decline in recycling) would justify an expenditure of $33,930 as fiscally neutral.

In the hypothetical case of no change in recycling, but reduced tonnage delivered for disposal (e.g. constant waste generation with increased private sector export to out-of-County facilities), it has been shown that the overall County savings is approximately $16.67/ton.

In this report, significant components of Montgomery County's solid waste management system costs, which costs reasonably can be predicted to respond to variations or shifts in tonnage, have been individually evaluated and placed into a unified framework. That framework: (1) enables evaluation of the principal system-wide budgetary effects of changes or shifts in tonnages of various types on overall County costs, (2) helps anticipate budget variances that may arise from tonnage-related externalities. Sensitivity and error analysis with respect to estimated parameters supports the general applicability of these findings.

The contract cost parameters used in this report were based on the estimates of those parameters used in preparing the County's FY07 budget. Contract costs change from year to year. Any policy based on the framework of analysis demonstrated here should be informed by additional a multi-year analysis.

Appendix A

Ash Fraction of Residential Mixed Paper

RMP Constituent	Fraction of Constituent in RMP (LB constituent / LB RMP) 2004 Outgoing	Breakouts	Ref.	Constituent Ash Fraction	Ref.	Ash in RMP (LB of Ash per LB of RMP Recycled)
Number 8 Grade	0.899		(a)			
Newspaper		0.504	(c)	1.4%	(c)	0.0071
Magazines		0.110	(c)	22.5%	(d)	0.0250
Direct Mail		0.110	(c)	13.1%	(d)	0.0146
Ledger paper		0.055	(c)	1.0%	(d)	0.0006
Other (Balance of No. 8)		0.120	(c)	5.9%	(e)	0.0071
OCC, including Kraft	0.091					
Kraft (Brown paper)		0.023	(b)	1.0%	(d)	0.0002
OCC (Corrugated)		0.068	(b)	5.1%	(d)	0.0035
Residue	0.010	0.010				
Total Ash Content of RMP Recycled (does not include residue)						**0.0581**

(a) OPS Budget Review, Consultant's Report (GBB), December 2004

(c) Breakouts of No. 8 and ash content of ONP per Frank Bernheisel, GBB, e-mail 10/13/05

(b) Breakout of OCC including Kraft per Harvey Gershman, GBB, telephone communication, 9/10/01

(d) Hasselriis, Floyd, "Refuse-Derived Fuel Processing, 1984 Ann Arbor Science

(e) Back-calculated as weighted average of above

Appendix B

Inert (Ash) Content of Typical Mix of Commingled Materials

Material Sold	Composition of Commingled Materials Recycled Through MRF *		Inert (Ash) as Mass Fraction of Individual Constituent	LB Ash Avoided / LB of Commingled Containers Recycled
	FY05 tons	wt. % of Total		
Plastic Bottles	3,907.06	17.73%	-	0.0000
Container Glass	15,367.80	69.74%	1.0000	0.6974
Aluminum	840.99	3.82%	1.0000	0.0382
Ferrous & Bimetal Cans	1,921.21	8.72%	1.0000	0.0872
Total	100.00%	100.00%		**0.8227**

* Individual MRF Outgoing Tons Normalized to One Ton of Total Outgoing to Market:
Source: DSWS

Appendix C

Commingled Materials Recovery Facility (MRF) Incremental Cost

				Reference / Comment
1	Operating Contract Costs			MES Sub-Object Code
2	Total Approved Invoices	$	2,504,658	FY05 Expense (a)
3	Throughput-Related Line-Items			Line-items assumed to be tonnage-proportional, over a range:
4	Maint./ Repair, Rolling Stock		45,626	FY05 Expense (a) 5704
5	Equipment Repair and Maint.		82,890	FY05 Expense (a) 5801
6	Building & Road Repair (1/2)		36,705	FY05 Expense (a) 5803
7	Contract Labor		819,489	FY05 Expense (a) 5829
8	Repair Parts		81,269	FY05 Expense (a) 5919
9	Grease & Lubricants		939	FY05 Expense (a) 5934
10	Baler Consumable Materials		31,368	FY05 Expense (a) 5936
11	Electricity (1/2)		43,295	FY05 Expense (a) 5602
12	Subtotal, Tonnage-Variable Expenses in FY05	$	1,141,579	Taken as the "tonnage-variable" portion of total contract cost paid
13	MRF Tonnage Throughput (Contanier Materials)		22,037	County Truck Scales, Outgoing from MRF during FY05
14	FY06 Tonnage-Variable MRF Operating Expense	$	51.80	/ton
15	Estimated Inflation FY07/FY05		4.96%	Est. by Consumer Price Index as surrogate, OMB est, for FY06 & FY07
16		$	54.37	/ton
17	Material Sales Revenue experienced in FY05	$	(3,146,213)	Revenue Posted to County, FAMIS 109 Report, 8/30/05
18	Material Sales Revenue, FY05, Average ton	$	(142.77)	/ton, Average Revenue per typical ton of Contanier Material, FY05
19	Estimated Inflation FY07/FY05		0.00%	Assumes no inflation or decline.
20	Material Sales Revenue, FY07, Average ton	$	(142.77)	/ton, Market prices actually vary considrably; large uncertainty introduced.
21	**Incremental Cost of MRF Operations.**	**$**	**(88.40)**	**/ton of typical commingled material, est., not a contract parameter**

Notes:

(a) Maryland Environmental Service (MES), Intergovernmental Agreement (IGA), Operating Expenditures, Invoice Detail

Appendix D
Sensitivity to Error in Assumed Tonnage-Tonnage Relationships

Results in Exhibits 4a and 4b, in the text, utilized ton-to-ton relationships derived from theory. The factors were: (A) the ash fraction, by weight, contained within Residential Mixed Paper, and (B) the ash fraction, by weight, comprising a standardized mix of commingled containers. These factors were necessary, in Section 3, in order to combine individual contract marginal costs to yield overall system effects. In as much as these were derived from text reference data rather than County specific measurements, it is fitting to consider the effect on the overall results of variation in those factors.

EXHIBIT D-1
ERROR ANALYSIS WITH RESPECT TO ESTIMATED ASH FRACTIONS

Sensitifity to Increase in Ash Fraction of RMP by *10%* **From 5.81%** **To 6.40%**

	Assumes Processible tons between 530,000 and 558,450	Processible tons > 558,450 and processsed all at RRF	Assumes all Incremental Tons Effect By-Pass Tonnage	
Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?	*$ -*	*$ -*	*$ -*	*/ ton avg. deliverable waste does not inlcude surge charges*
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?				
RMP < 90,000 TPY	*$ (0.23)*	*$ (0.23)*	*$ -*	*/ ton of paper shifted*
RMP > 90,000 TPY	*$ (0.23)*	*$ (0.23)*	*$ -*	*/ ton of paper shifted*
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?	*$ 0.00*	*$ 0.00*	*$ 0.00*	*/ ton of commingled*
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?				
RMP < 90,000 TPY	*$ (0.17)*	*$ (0.17)*	*$ 0.00*	*/ ton increased recycling*
RMP > 90,000 TPY	*$ (0.17)*	*$ (0.17)*	*$ 0.00*	*/ ton increased recycling*

(Expressed in FY07 dollars)

Sensitivity to Increased Container Ash Fraction by *10%* **From 82.30%** **To 90.53%**

	Assumes Processible tons between 530,000 and 558,450	Processible tons > 558,450 and processsed all at RRF	Assumes all Incremental Tons Effect By-Pass Tonnage	
Q1 …if one LESS ton of typical waste is delivered for disposal to the County with no change in recycling?	*$ -*	*$ -*	*$ -*	*/ ton avg. deliverable waste does not inlcude surge charges*
Q2 …if one ton of residential mixed paper (RMP) is SHIFTED from trash can to recycling bin?				
RMP < 90,000 TPY	*$ -*	*$ -*	*$ -*	*/ ton of paper shifted*
RMP > 90,000 TPY	*$ -*	*$ -*	*$ -*	*/ ton of paper shifted*
Q3 …if one ton of residential commingled containers is SHIFTED from trash can to recycling bin?	*$ (3.22)*	*$ (3.22)*	*$ 0.00*	*/ ton of commingled*
Q4 …if one ton, comprised of both paper and containers, is SHIFTED from trash can to recycling bin?				
RMP < 90,000 TPY	*$ (0.76)*	*$ (0.76)*	*$ 0.00*	*/ ton increased recycling*
RMP > 90,000 TPY	*$ (0.76)*	*$ (0.76)*	*$ 0.00*	*/ ton increased recycling*

(Expressed in FY07 dollars)

Exhibit D-1, above, shows the effects of increasing each of these factors by 10% (a degree of error thought to be very unlikely.) The overall effects are minor. Increasing the estimated ash fraction of RMP by 10% (e.g. from 5.81% to 6.41%) reduces the answers to Q2 in Exhibit 4a and 4b by 23 cents, and Q4 in those exhibits by 17 cents. Increasing the assumed ash fraction of Commingled containers recycled by 10% (e.g. from 82.3% to 90.53%) reduces the answers to Q3 in Exhibit 4a and 4b by $3.22/ton, and Q4 in those exhibits by $0.76/ton.

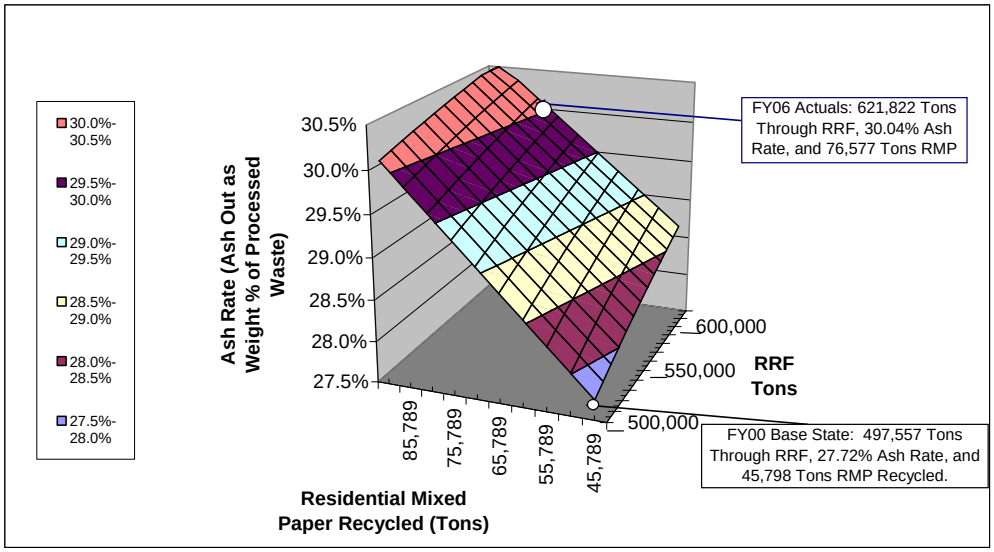
Appendix E
Sensitivity to Potential Second-Order Effects

This appendix examines potential secondary, or non-linear, effects on RRF operations, which effects might result from the changing composition of the waste disposed, and thus delivered to the RRF for processing. Two potential second-order effects are assessed. One is the effect of recycling diversion on the ash content of waste delivered to the RRF. The other is that of increased recycling diversions on the higher heating value (HHV) of disposed waste. (The HHV of a material is defined in terms of its extractable energy content per unit of mass, typically expressed in terms of Btu/lb).

Effects of Recycling Diversion on RRF Ash Content of Disposed Waste

Potential secondary effects of both paper and container recycling are illustrated by theoretical calculation. An increase in paper recycling (shifting paper from trash to recycling) can increase the rate of ash generation at the RRF. This numerical effect is inexorable *if* the RRF tonnage remains constant, replaced ton-for-ton, by material having any higher ash content than that of the RMP recycled, *and if other operating conditions remain the same*. Since the ash content of RMP is low (about 6%) compared to typical waste (about 27+%) a slight increase in ash generation rate has accompanied increases in recycling. The mathematical result of these assumptions is illustrated in Exhibit E-1 below.

Exhibit E-1



The effect is minor on an incremental cost basis, adding less than $1.00 in ash handling costs per incremental ton of paper diverted from disposal. Moreover, this result assumes replacement in the RRF by waste of undiminished residue content; even this small effect will be diminished as more paper recycling occurs system-wide, including the waste sources generating the "replacement" waste.

The considerations are similar in the case of commingled container recycling, but due to the relatively high ash content of commingled containers (82 wt. % for the typical container

mix) the economic effect is reversed, though still relatively small. The more container mix is diverted, the lower the ash handling costs, enhancing the general system-wise results, expressed in Exhibits 1 and 6 in the text, that increased recycling diversion reduced County system costs.

Effects of Recycling Diversions on Higher Heating Value of Waste Delivered to the RRF

In the preceding analysis electricity sales credited against the County's operating cost are taken as precisely proportional to tonnage processed. That is, the values in Exhibit 3, at references "G" and "G1", presume that the HHV of the waste delivered to the RRF is constant and unaltered regardless of which waste constituents are diverted from the disposed waste stream (e.g. to recycling) and how many tons of such diversion are achieved. All else being equal—such as the unit prices paid for electricity and various plant efficiencies—this is a reasonable assumption, provided that the HHV of the waste processed at the RRF remains unaltered. However, the HHV of any waste is the weighted-average of the individual HHV values of its constituent materials. Thus, it can be understood that augmenting the composition of a waste can inherently augment its overall HHV, the result depending upon the individual HHV properties, and relative weight composition, of the each of the species comprising the waste, and those diverted from it. Furthermore, those hypothetical cases expressed in questions Q2, Q3, and Q4, pose that tonnage delivered to the RRF is decreased as a result of diverting from disposal (e.g. removing) *certain species of waste*. Thus, it stands to reason that under the conditions posed by Q2, Q3, and Q4, the aggregate HHV of the remaining waste delivered to the RRF might be altered by the very act of recycling diversion. To the extent that this is the case, the resulting marginal cost itself (e.g. of RRF processing) would change with increasing diversion. This is called a second-order effect. Second-order effects cause marginal costs to vary with increasing or decreasing tonnage (and the slope in a cost-versus-tonnage graph to becomes curved).

Calculations presented in Exhibit E-2 examine the potential second-order effects of recycling diversions on RRF marginal costs due to HHV augmentation. Separate cases are examined for the diversion of commingled containers and residential mixed paper. Adjustment values are calculated that can be applied to the Exhibit-3 values of G and G1 to account for altered HHV given more and more diversions of selected recyclables from the waste entering the RRF. The exhibit demonstrates that second-order HHV effects are quite small, effects from container recycling being larger than those of RMP recycling, but the former not changing the Exhibit 3 values for G1 and G2 by more than about 11 cents per ton.

Negative values in the exhibit indicate additional savings to the County with increasing container diversions, but the effect is so small as to be considered insignificant. For example, once an additional 10,000 tons of commingled container-type materials is diverted from the waste otherwise headed for the RRF, all other conditions being equal, the County's marginal costs for RRF processing would be $0.03/ton lower than indicated in Exhibit 3. For example, in the case of an annual tonnage throughput in the range of 558,450 to 657,000 the marginal RRF marginal cost given in Exhibit 3 changes from $3.86/ton to $3.83/ton. The composition of material diverted in that case was that of the average mix of commingled containers received at the County MRF. The case of diverting residential mixed paper is also calculated in Exhibit E-2, but in that case the HHV effects of waste augmentation by virtue of paper recycling are found to be even less significant.

Exhibit E-2
Effects of Recycling Diversions on Higher Heating Value (HHV) of Waste Processed and Adjustment Values

Definitions:

D =	(tons)	the number of tons diverted
Mb =	(tons)	Processible waste throughput, base case, before incremental diversion of any incremental recyclable constituents
Rb =	(tons)	Total tons of D-type materials in Mb before diversion
Hb =	(Btu/lb)	HHV of the overall waste expected to be processed at the RRF, base case, unaugmented by virtue of any diversion.
Hr =	(Btu/lb)	Specific HHV of the mix of recyclabe materials of the D-type materials being diverted (e.g. removed from the RRF-processed waste stream)
Ho =	(Btu/lb)	Aggregate HHV of the balance of materials in the disposed waste other than d-type materials (does not change with diversion)
H(D) =	(Btu/lb)	HHV of the remaining, agumented waste after D tons of subject recyclable waste have been diverted from RRF.
Eb =	($/ton)	Average Electric Rev./ton of waste processed; base case; all unaltered waste.
E(D) =	($/ton)	Average Electric Rev./ton of the waste stream processed, as agumented by diversion of D tons such that HHV = Ho.

For the case of unaltered waste, we have the relationship:

Hb (Btu/lb) * 2000 (lb/ton) * C ($/Btu) = Eb ($/ton) **Equation (1)**

where C = a constant reflecting electric sales per realizable BTU content of waste processed, and

which can be restated, more generally, for any D tons diverted:

E(D) = H(D) * 2000 * C **Equation (2)**

which assumes that electricity sales is linearly related to the HHV of the waste (as is asumed in the contract model, and that this is via a constant, C, the value of which can be solved for any known case, such as our base case.

Now, given that:

Hb =	5,363	(Btu/lb)	(FY05 actual, by facility calorimetery), and
Eb =	(27.747)	($/ton)	from latest RRF contract model, FY07 dollars

(Boxed values represent inputs.)

Equation (1) yields:

C = -2.5869E-06 ($/Btu) Electric Sales revenue per unit of Btu heating value in waste processed

Finally, from the additive property of higher heating values, we may derive, by weighted-averaging, that:

H(D) = [Hr*(Rb-D) + Ho*(Mb-Rb)]/(Mb-D) **Equation (3)**

Hr and Rb are solved in the footnoted table for two cases examined: diverting mixed paper, and, alternately, a standard commingled container mix.

Now, we can examine the effects on HHV and energy revenue of diverting from RRF waste various types of materials.

In all cases, we will assume Mb = 610,000 (tons) to RRF [**INPUT**]

Case 1: Diversion of Mixed Paper; provides adjustment values relative to Question 3 in the text.

Hr = 5,412 (Btu/lb) of the materials diverted from disposal to recycling, from Footnote Calculations

and Rb = 181,420 also from Footnote Calculation

Results Table:	D (tons)	0	15,000	30,000	45,000	60,000	75,000	90,000	105,000
By Eq. (3):	H(D) (Btu/lb)	5,363	5,362	5,360	5,359	5,358	5,356	5,354	5,353
By Eq. (2):	E(D) ($/ton)	$ (27.747)	$ (27.740)	$ (27.734)	$ (27.727)	$ (27.719)	$ (27.711)	$ (27.703)	$ (27.694)
Adjustments to G1 & G2 ($/ton)		$ -	$ 0.01	$ 0.01	$ 0.02	$ 0.03	$ 0.04	$ 0.04	$ 0.05

Case 2: Diversion of Cominngled Containers; provides adjustment values relative to Question 2 in the text.

Hr = 5,001 (Btu/lb) of the materials diverted from disposal to recycling, from Footnote Calculations

and Rb = 28,980 also from Footnote Calculation

Results Table:	D (tons)	0	5,000	10,000	15,000	20,000	25,000	30,000	35,000
By Eq. (3):	H(D) (Btu/lb)	5,363	5,366	5,369	5,372	5,375	5,378	5,382	5,385
By Eq. (2):	E(D) ($/ton)	$ (27.747)	$ (27.762)	$ (27.778)	$ (27.794)	$ (27.810)	$ (27.827)	$ (27.844)	$ (27.861)
Adjustments to G1 & G2 ($/ton)		$ -	$ (0.02)	$ (0.03)	$ (0.05)	$ (0.06)	$ (0.08)	$ (0.10)	$ (0.11)

Calculations of Hr, Rb, and Ho:

Waste Constituent	HHV (Btu/lb)		Weigth Fraction (d)	Weigth Fraction	Group **Rb** tons
Newspaper	6188	(a)	4.24%		
Kraft (Brown paper)	5289	(b)	0.44%		
OCC (Corrugated)	5658	(a)	10.68%		
Magazines	4420	(a)	2.93%		
Direct Mail	4986	(a)	4.07%		
Ledger Paper	5180	(a)	3.33%		
Other Paper	5304	(a)	4.07%		
Group Subtotal, Mixed Paper				29.74%	**181,420**
Plastic Bottles	15334	(a)	1.53%		
Container Glass	69	(a)	2.13%		
Aluminum	0	(a)	0.38%		
Ferrous & Bi metal Cans	247	(a)	0.71%		
Group Subtotal, Commingled Containers				4.75%	**28,980**
Remainder (solved)	3,516	(c)	65.51%		
Total to RRF, Base, Unaltered Case			100.00%		610,000

	29.74%		
		4.75%	
	70.26%	95.25%	
	100.00%	100.00%	

	Fractional Btu/lb	Subtotal of Fractional Btu/lb	Group **Hr** Btu/lb
Newspaper	262		
Kraft (Brown paper)	23		
OCC (Corrugated)	604		
Magazines	129		
Direct Mail	203		
Ledger Paper	172		
Other Paper	216		
Group Subtotal, Mixed Paper		1,610	**5,412**
Plastic Bottles	234		
Container Glass	1		
Aluminum	-		
Ferrous & Bi metal Cans	2		
Group Subtotal, Commingled Containers		238	**5,001**
Remainder (solved) (c)	3,516	3,516	5,367
Total HHV of Unaltered Waste (e)	5,363	5,363	

Ho Btu/lb	**Ho** Btu/lb
For Materials **other than Paper** in the disposed waste	For Materials **other than Containers** in the disposed waste
5,342	5,381

(a) Wet weight basis, adapted from Harrison et al., June 2000

(b) Avg. of other paper constituents

(c) Solved for

(d) Montgomery County Solid Waste Composition Study, 2004

(e) Actual HHV of waste processed at the RRF during FY05, by Facility calorimitor